

Canadian Institute of  
Guided Ground Transport  
Queen's University  
at Kingston, Ontario

G.J. Clouston  
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CIGGT Report No. 88-6  
Transport Canada Report No. TP-9518E

prepared for  
Transportation Development Centre  
Policy and Coordination Group  
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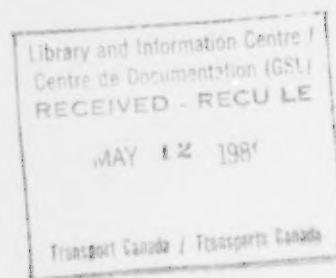
## LOW-FRICTION SNOW PLOW EVALUATION

prepared for

Transportation Development Centre  
Policy and Coordination Group  
Transport Canada

by

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## EXECUTIVE SUMMARY

Snow plows play an important role in Canadian railway operations. Traffic is delayed until lines are cleared of snow following heavy snow falls. A modification which would permit higher plowing speeds and fewer delays could realize significant benefits in addition to the direct fuel and labour savings.

Low-friction polymer coatings have been used on snow plows in both highway and airport applications. The objective of this project was to carry out a cost benefit analysis on a low-friction coating applied to a mainline railway snow plow. The assessment was carried out in cooperation with the Canadian National Railway (CN Rail), using two of their snow plows for test purposes. Due to lack of snow storms and early equipment problems, an analytical model was developed to estimate the importance of friction reduction to fuel consumption and power requirements.

The sensitivity analysis revealed a bump or discontinuity in the power vs. speed profile. This bump corresponds to the minimum plow speed at which the snow will cease to flow over the plow, and will instead pile up in front of the plow. Reducing the coefficient of friction reduces this minimum plowing speed. This could mean the difference between success and failure in plowing some tight, heavily laden snow drifts. However, the analysis also revealed that the coefficient of friction does not seem to drastically alter the power required to plow snow above the minimum speed.

A qualitative assessment of the benefits of the low-friction coating was made by the plow crews. After two winters of service, the coating to the body surfaces had not visibly deteriorated. The plow face did have several spots where the coating had been abrasively removed. They were generally near the top of the plow face.

On the basis of theoretical analysis alone, it appears that low-friction coatings of railway snow plows do not meet a hurdle level return on investment of 15%. Fuel savings are estimated to be minimal and the labour savings offer about an 11% return on investment under the better of two scenarios. However, the indirect benefits of reduced train delays would only have to be in the range of \$250 to \$300 annually to provide a 15% real return on investment for this scenario.

## SOMMAIRE

Les réseaux ferroviaires du Canada comptent sur le déneigement des voies afin d'éviter que la circulation des trains ne soit indûment retardée après une forte chute de neige. La mise en service d'un chasse-neige plus rapide et occasionnant moins de temps morts serait un atout pour ces réseaux et leur ferait réaliser de fortes économies sur les coûts directs d'exploitation : consommation et salaires.

Des matériels chasse-neige recouverts d'un polymère à faible coefficient de frottement servent depuis fort longtemps au déneigement des voies ferrées et des aéroports. La présente recherche visait à mettre en évidence les avantages technico-économiques d'un tel revêtement appliqué à un chasse-neige du type utilisé pour le déneigement des grandes lignes. CN Rail a participé directement à cette recherche, en plus de permettre l'utilisation de deux de ses chasse-neige. En raison de l'absence de neige abondante et des ennuis mécaniques en début des travaux, les chercheurs ont dû élaborer un modèle analytique susceptible de déterminer l'effet d'une réduction du frottement sur la consommation et les puissances de traction.

L'analyse de sensibilité a mis en évidence une discontinuité dans les courbes puissances de traction-vitesses, qui correspond à la vitesse de déneigement au-dessous de laquelle l'inertie de la neige commence à l'emporter sur la dynamique du chasse-neige. L'avantage d'une réduction du coefficient de frottement réside dans la réduction de cette vitesse minimale ou bien dans la possibilité de s'attaquer à des accumulations de neige lourde et bien tassée. Cette analyse a également montré qu'une telle réduction du frottement n'a aucun effet mesurable sur les puissances de traction aux vitesses de déneigement supérieures.

Les équipes de déneigement ont eu l'occasion de procéder à une évaluation qualitative de l'effet du revêtement anti-frottement. Au bout de deux hivers, aucune détérioration significative du revêtement n'a été observée, à part quelques traces d'usure abrasive en certains endroits de la face du chasse-neige, concentrées dans sa partie supérieure.

Les calculs analytiques montrent que le rendement financier pour les réseaux ferroviaires qui adopteraient ce procédé pourrait difficilement atteindre 15% (le minimum demandé). Les économies de combustible seraient négligeables, tandis qu'au niveau des salaires, elles seraient l'équivalent d'un rendement financier de quelque 11%, dans le meilleur des deux cas possibles. Par contre, la réduction des coûts indirects consécutive à une réduction des retards sur les horaires devrait être de l'ordre de 250 à 300 \$ par an afin d'équivaloir à un rendement financier net de 25%.

## TABLE OF CONTENTS

|                                            |                                       |    |
|--------------------------------------------|---------------------------------------|----|
| 1.                                         | INTRODUCTION .....                    | 1  |
| 2.                                         | PROCEDURE .....                       | 2  |
| 2.1                                        | Analytic Work .....                   | 4  |
| 2.2                                        | Snow Plow Model Sensitivities .....   | 4  |
| 2.3                                        | Plow-Train Simulations .....          | 8  |
| 2.4                                        | Qualitative Assessment .....          | 8  |
| 3.                                         | FINANCIAL BENEFITS .....              | 11 |
| 4.                                         | CONCLUSIONS AND RECOMMENDATIONS ..... | 12 |
| Appendix A: POWER REQUIREMENTS OF V PLOWS  |                                       |    |
| Appendix B: FUEL CONSUMPTION/NETWORK PLOTS |                                       |    |

## LIST OF FIGURES

|    |                                                                        |   |
|----|------------------------------------------------------------------------|---|
| 1. | Sensitivity to Coefficient of Friction . . . . .                       | 5 |
| 2. | Sensitivity to Length of Horizontal Wedge . . . . .                    | 5 |
| 3. | Sensitivity to Angle of Vertical Wedge . . . . .                       | 6 |
| 4. | Sensitivity to Angle of Horizontal Wedge . . . . .                     | 6 |
| 5. | Sensitivity to Snow Depth Variation . . . . .                          | 7 |
| 6. | Sensitivity to Snow Density Variation . . . . .                        | 7 |
| 7. | Coupler Force for 6.1 Foot (2 Metre) Drift with .10 Friction . . . . . | 9 |
| 8. | Coupler Force for 6.1 Foot (2 Metre) Drift with .02 Friction . . . . . | 9 |

## LIST OF PLATES

|    |                                                                                |    |
|----|--------------------------------------------------------------------------------|----|
| 1. | Jordon Model No. 556 Snow Plow . . . . .                                       | 2  |
| 2. | Photograph of Sample Test Section . . . . .                                    | 3  |
| 3. | Photograph of Sample Test Section . . . . .                                    | 3  |
| 4. | Picture of Plow Face Showing Snow Adherence<br>to Protruding Coupler . . . . . | 10 |
| 5. | Deterioration of Plow Face Coating After Two Winters . . . . .                 | 10 |

## 1. INTRODUCTION

Low-friction polymer coatings have been used on snow plows in both highway and airport applications. While visibility of the orange colour used in the polymers was a cited benefit, fuel savings have also been reported. Snow plows play an important role in Canadian railway operations. Traffic is delayed until lines are cleared of snow following heavy snow falls. A modification which would permit higher plowing speeds and fewer delays could realize significant benefits in addition to the direct fuel and labour savings.

The objective of this project was to carry out a cost benefit analysis on a low-friction coating applied to a mainline railway snow plow. The assessment was carried out in cooperation with the Canadian National Railway (CN Rail), using two of their snow plows for test purposes.

The railway industry has historically used imperial units to denote train resistancy. Many of the established coefficients are difficult to interpret if converted to metric measures. Therefore, for this report, it was decided that Imperial units would be adopted throughout.

## 2. PROCEDURE

A CN Rail snow plow (Jordan Model No. 55614, illustrated in Plate #1) was coated with "Devron 188," a high-technology epoxy coating which was originally designed for and used on ice breaker hulls. All exposed surfaces of the plow were coated, as an anticipated benefit of having a low-friction body was the ability to more easily extract the plow when it became wedged in a deep bank of snow. The plow was equipped with a train data recording system, an instrumented drawbar and a radar speed sensor.

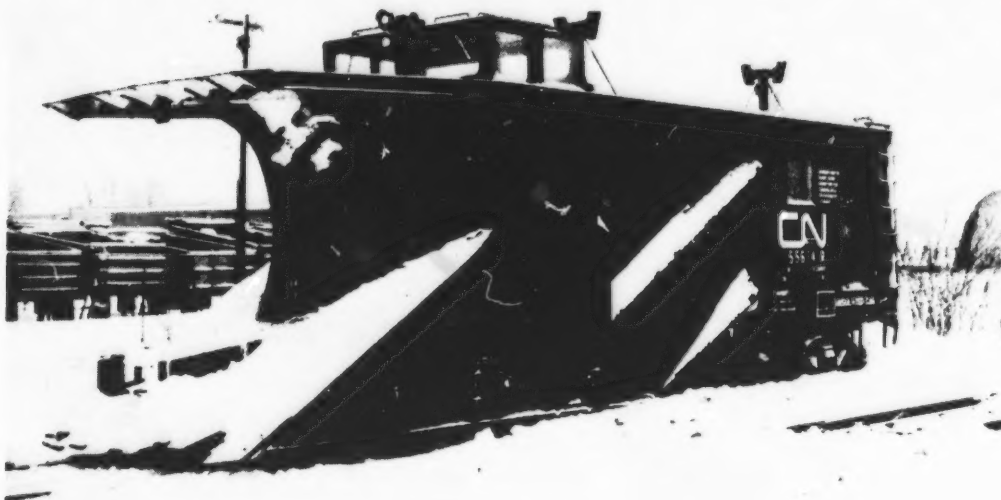


**Plate #1 Jordan Model No. 556 Snow Plow**

Five test sections of one-half mile each were selected from the Thorndale, Goderich and Exeter Subdivisions near London, Ontario (Plates #2 and #3). Snow depth and density were to be measured at each site.

In addition, the crews were asked to fill in a form after each snow clearing trip indicating the time required to clear the plow of snow.

The original plan was to develop an analytical snow plow model using experimental data, and apply the model to various operating scenarios in a simulation. Unfortunately, over the two winters that these data were intended to be gathered, there was not a significant number of snow storms and there were early equipment problems.



**Plate #2** Photograph of Sample Test Section



**Plate #3** Photograph of Sample Test Section

## 2.1 Analytic Work

It was decided to develop an analytical model and test it with available train simulators to estimate the importance of friction reduction to fuel consumption and power requirements.

A rather simplistic snow plow model was developed on the assumption that the snow flowing over a simplified V plow could be modeled as a sheet of snow and that the interactive forces between the snow particles could be neglected without introducing a serious error. The assumptions and model development are in Appendix A.

## 2.2 Snow Plow Model Sensitivities

To obtain a feeling for the role of each parameter in the snow plow model, six sensitivity plots were made (Figures 1 through 6) by changing one variable over a specified range and then plotting the variation using a velocity vs horsepower graph. The sensitivity plots demonstrate a bump or discontinuity in each of the graphs. This bump corresponds to the minimum plow speed at which the snow will cease to flow over the plow, and will instead pile up in front of the plow. The last page in the appendix contains a plot of the minimum plow speed vs the coefficient of friction for the wedge angles used in the snow plow model. The plot shows quite dramatically that reducing the coefficient of friction also reduces the minimum plowing speed. It should be noted that all the sensitivity plots show a basic cubic shape since the power is a function of velocity cubed.

As might be expected from the sensitivity graphs, the snow density and snow depth are very important to the amount of power required to plow snow. Physically, this relates to the fact that the deeper and denser the snow, the more weight and volume of snow that must be plowed.

The angle of the wedges also display significant variations in horsepower required since the angles specify the change in direction (and therefore momentum) that the plow must exert on the snow.

An interesting result is that the coefficient of friction does not seem to drastically alter the power required to plow snow. The coefficient of friction plot shows a dramatic change below the minimum plow speed, but above the minimum speed, little change is apparent. The length of the horizontal wedge plot, which specifies the distance that work against friction must be applied, shows basically the same results.

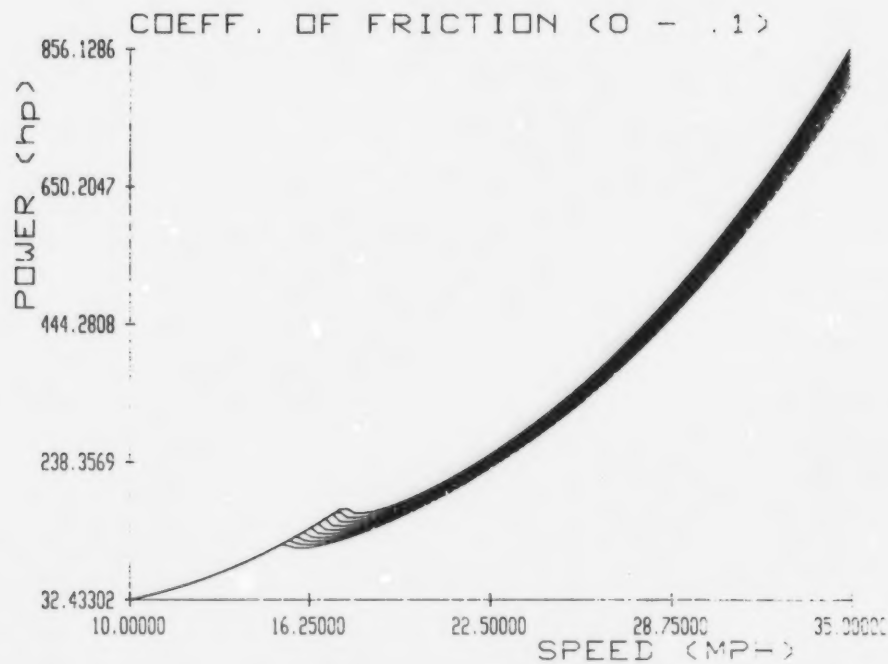


Figure 1 Sensitivity to Coefficient of Friction

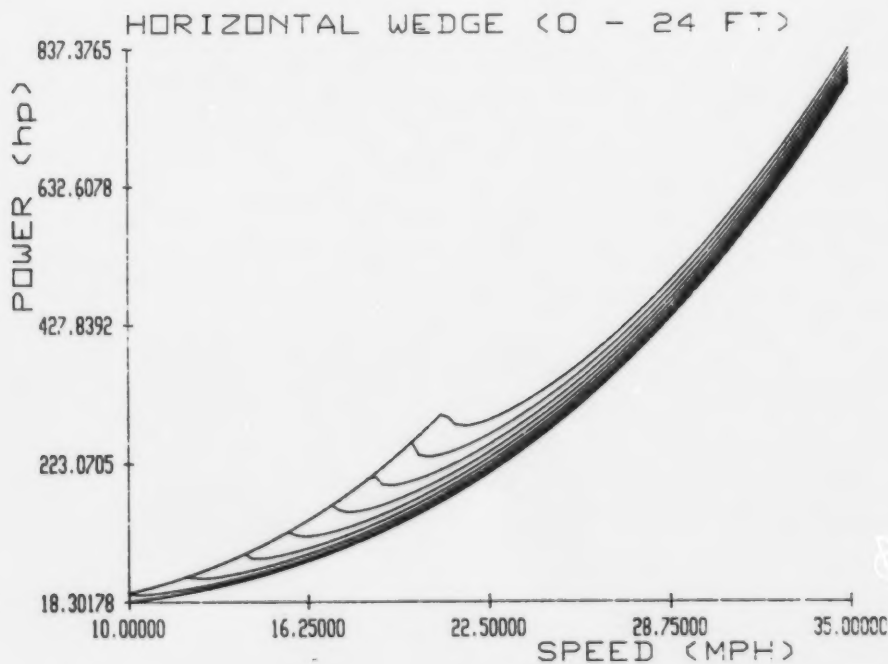


Figure 2 Sensitivity to Length of Horizontal Wedge

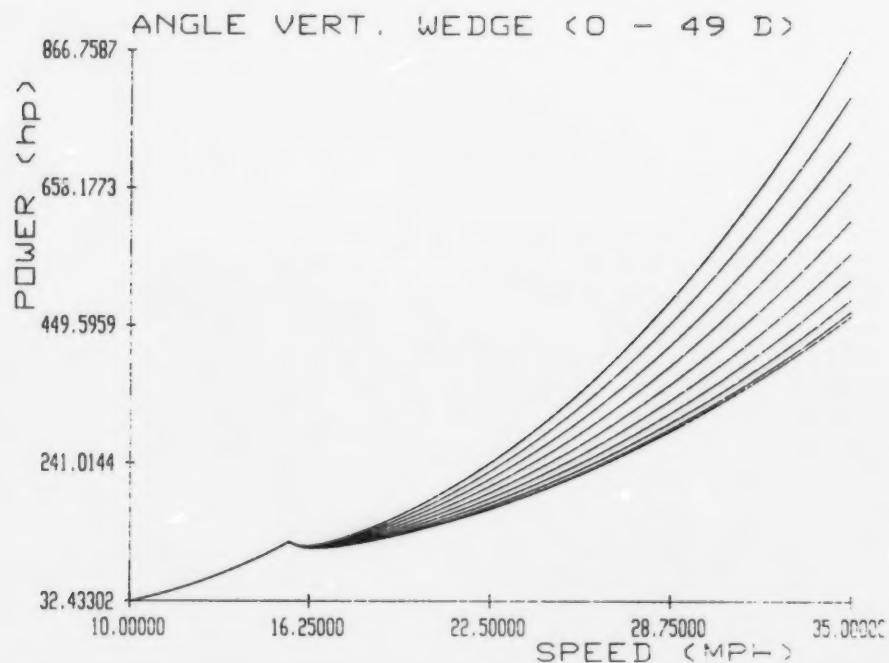


Figure 3 Sensitivity to Angle of Vertical Wedge

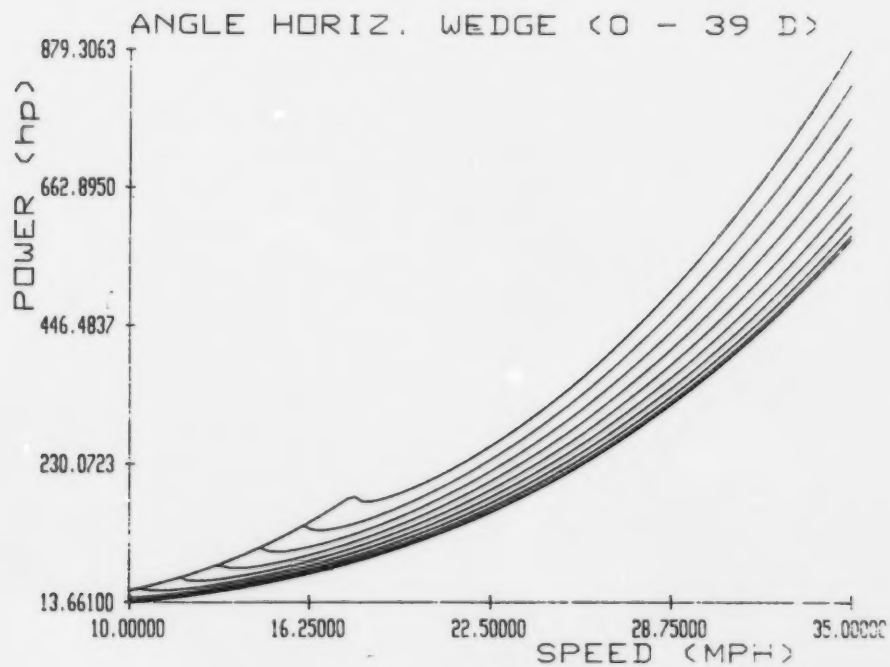


Figure 4 Sensitivity to Angle of Horizontal Wedge

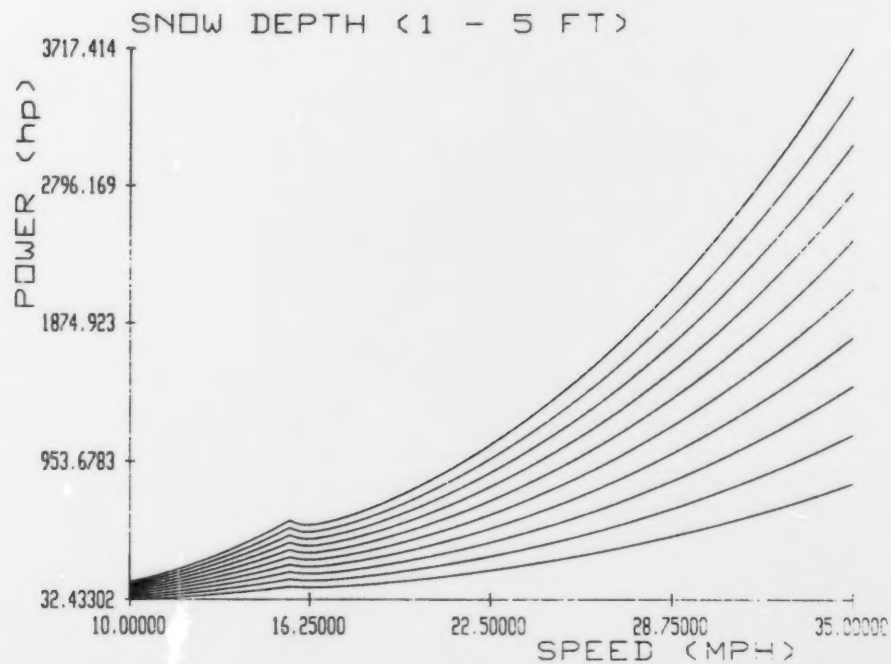


Figure 5 Sensitivity to Snow Depth Variation

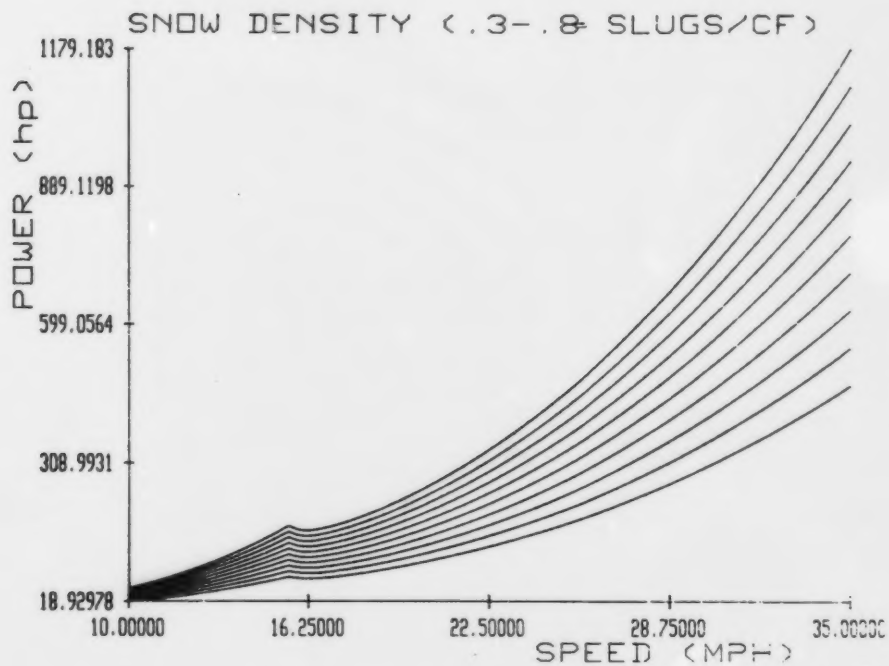


Figure 6 Sensitivity to Snow Density Variation

### 2.3 Plow-Train Simulations

The plow model was then integrated into a modified version of a train performance calculator. A train consist was put together that consisted of a snow plow, lab car, and two GP09 locomotives. In total, 561 runs were made with Train Energy Model (TEM) while varying the plowing speed, snow depth, and coefficient of friction on ten miles of straight and level track. The output of these runs (fuel used and net work done by the locomotives) and can be found in graphical form in Appendix B.

Appendix B shows the graphical results from the simulation runs. In all cases, plots of both work and fuel used show very little change due the coefficient of friction.

Another train model, the Freight Train Simulator (FTS), was used to get a feeling for the speed reduction and coupler forces experienced when the train consist encountered a drift. Figures 7 and 8 simulate the plow going through a 6.1 foot (2 metre drift). Both runs used identical input parameters except that the first plot used a coefficient of friction of 0.10 while the second plot used a coefficient of 0.02. The effect of the coefficient of friction appears to be minimal as the two plots are almost identical.

### 2.4 Qualitative Assessment

In addition, a qualitative assessment of the benefits of the low-friction coating was made by the plow crews.

They felt that the plow was less susceptible to getting stuck in deep snow cuts. The one time that it did happen, it was easily extracted. This is an important benefit as normal plows sometimes require additional engines to be called in to extract a stuck plow train. The incidence of snow retention was also reduced. When snow did adhere to the plow (usually to the nose coupler, as seen in Plate #4) it was easily cleaned off. The average saving was estimated to be thirty minutes per plow call.

The condition of the plow was checked after two winters of service. The coating to the body surfaces had not visibly deteriorated. The plow face did have several spots where the coating had been abrasively removed (Plate #5). These spots averaged about .75 inches (1.65 cm) in diameter. They were generally near the top of the plow face.

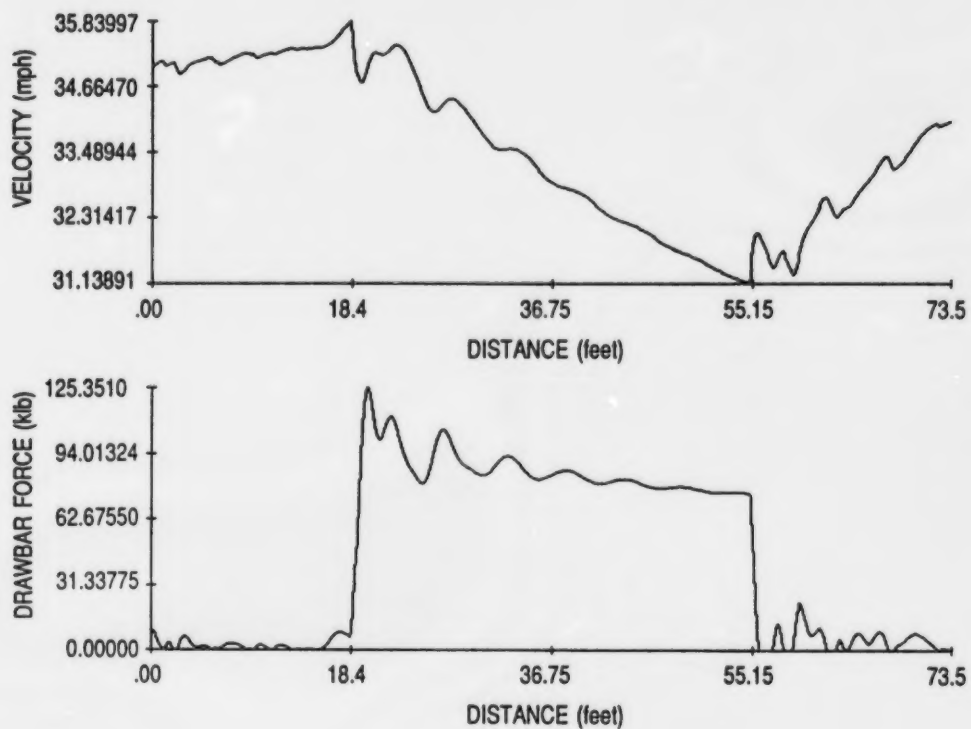


**Figure 7 Coupler Force for 6.1 Foot (2 Metre) Drift with .10 Friction**

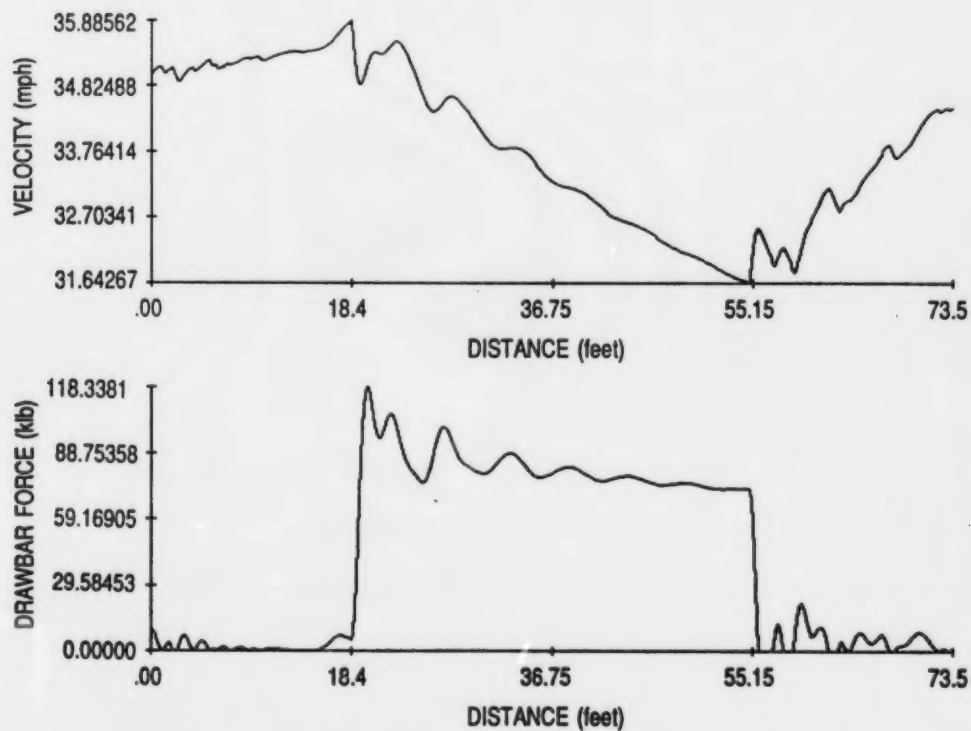


**Figure 8 Coupler Force for 6.1 Foot (2 Metre) Drift with .02 Friction**



**Plate #4** Picture of Plow Face Showing Snow Adherence to Protruding Coupler

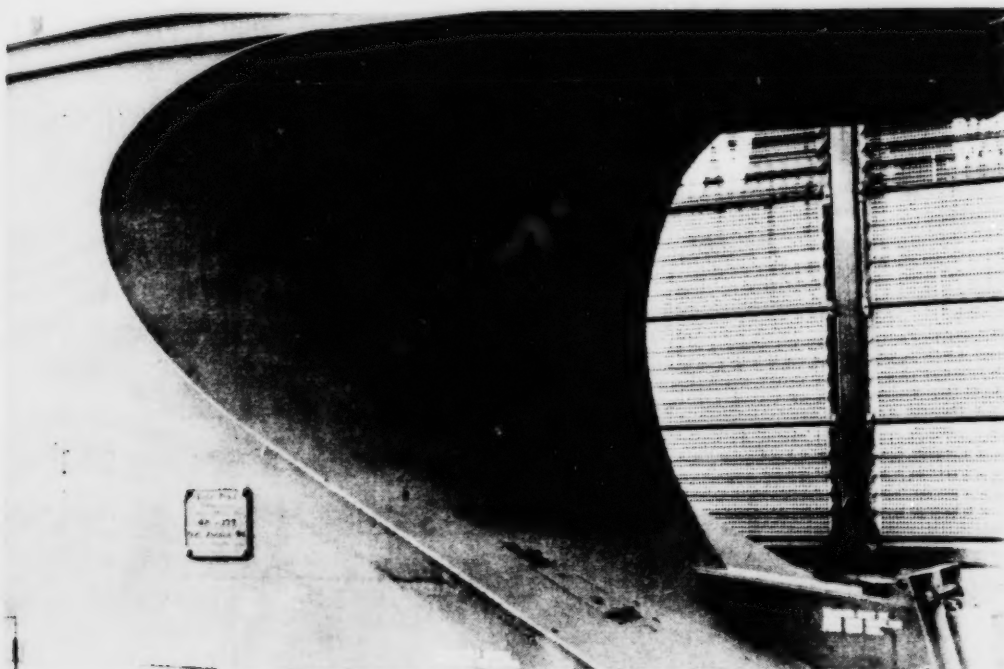


**Plate #5** Deterioration of Plow Face Coating After Two Winters

### 3. FINANCIAL BENEFITS

The benefits from shorter plow cleanup times are estimated to be in the order of \$500 annually. On the basis of this analysis, it would appear that the money saved on fuel by using low-friction coatings is not substantial. The analysis does indicate, however, that the minimum plowing speed can be substantially reduced by lowering the coefficient of friction. This could mean the difference between success and failure in plowing some tight, heavily laden snow drifts. The benefit has been estimated to be an average 15 minute reduction in plowing time (elimination of a 1 hour delay every four times out). The direct benefits are in the order of \$250 annually. The indirect delay costs to waiting trains are difficult to quantify.

The cost of coating a complete plow was estimated to be \$20,000. composed of \$12,000 material and \$8,000 labour-and-transportation. Recoating has been assumed to be required at 10 years for the plow face at 20 years for the body. As the plow is normally painted with conventional paint at this interval the incremental cost is actually about \$6,000.

The return on investment has been assessed under two scenarios. The first assumes that plows are converted immediately, while the second assumes that a plow is converted only when it is due for a normal repainting. On the basis of the first scenario the direct benefits provide less than a 4% return on investment. The second scenario has an 11% return. However, the indirect benefits of reduced train delays would only have to be in the range of \$250 to \$300 annually to provide a 15 % real return on investment for this scenario. The first scenario would require a \$2,500 to \$3,000 increment to provide the same return. This may be realized in mainline territory with frequent snowfalls but not on a system wide basis.

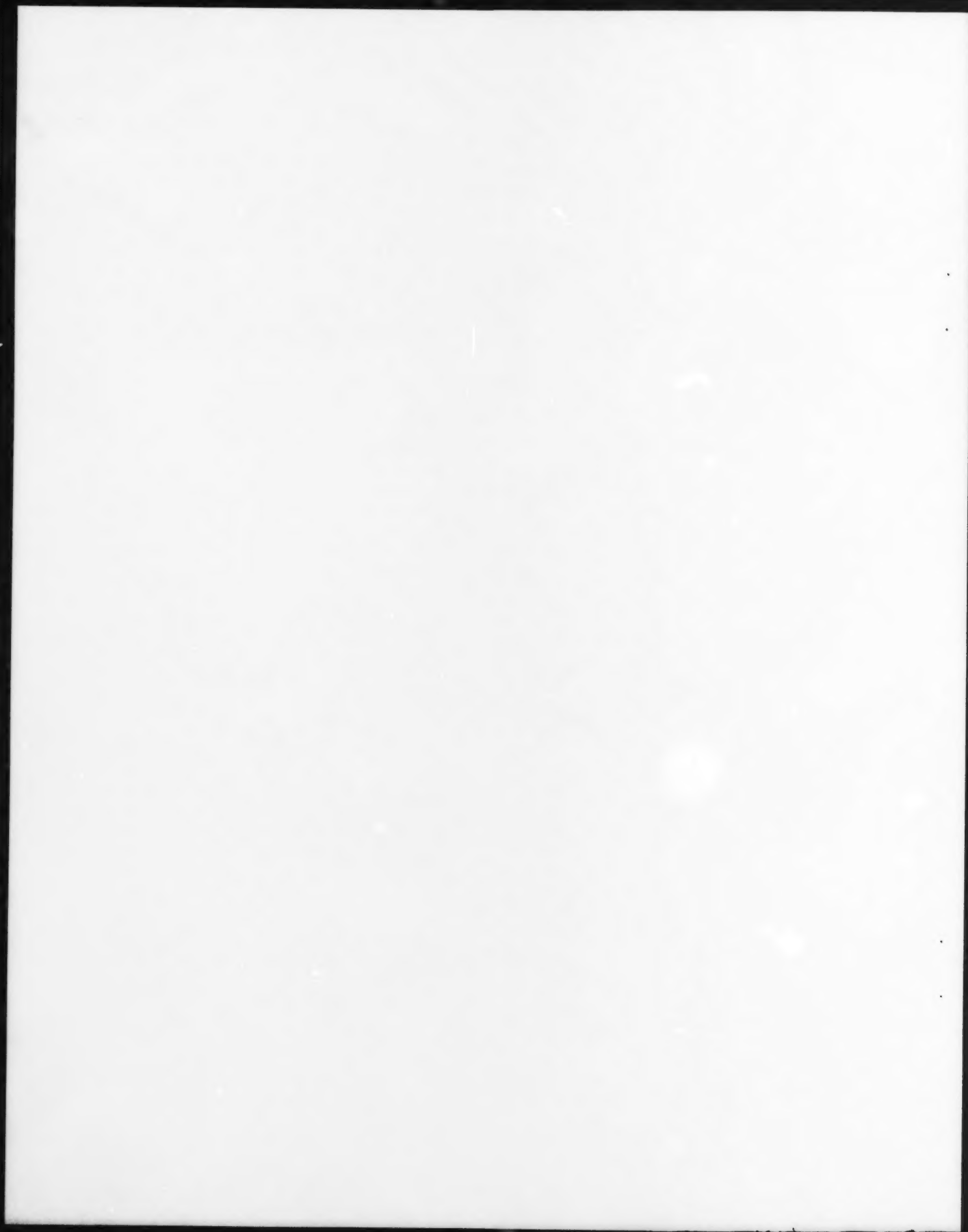
#### **4. CONCLUSIONS AND RECOMMENDATIONS**

On the basis of theoretical analysis alone it appears that low friction coatings of railway snowplows does not meet a hurdle level return on investment. Fuel savings are estimated to be minimal and the labour savings offer an 11% return on investment.

The paint coating tested demonstrated an acceptable level of endurance for the two-year test period.

There is an analytic prediction and a qualitative assessment of a reduced propensity to get a plow stuck in deep drifts. An indirect benefit is reduced train delays waiting for line clearing. It is recommended that the frequency of mainline plows getting stuck and number of train delays for snow clearing be surveyed in order to assess the magnitude of the potential indirect benefits.

**APPENDIX A**  
**POWER REQUIREMENTS OF V PLOWS**



## APPENDIX A

### POWER REQUIREMENTS OF V PLOWS

The following is a brief mathematical examination of the dynamics involved in the plowing of snow. The fundamental assumption made throughout this analysis was that the interactive forces between the snow particles could be neglected without introducing a serious error. The validity of this assumption has yet to be established through the use of experimental testing.

The following symbols are used:

- $V_1$  = velocity of advance of snow plow
- $V_2$  = velocity of snow over the leading edge of the wedge
- $V_3$  = velocity of exit of snow sheet from the wedge surface
- $A$  = cross-sectional area of plowed snow
- $\rho$  = mass density of snow
- $\mu$  = coefficient of friction between snow and wedge surface
- $\alpha$  = angle of elevation wedge
- $\beta$  = angle of vertical wedge
- $l$  = length of wedge surface in direction of travel
- $c$  = ratio of exit velocity to velocity of plow, i.e.  $c = V_3/V_1$ .

Consider the simple elevation wedge shown in Figure A.1. As the wedge advances through the snow a distance  $S_1$ , a particle of snow will be displaced a distance  $X$  in the direction of travel, and it will also move a distance  $S_3$  along the surface of the wedge. Ideally,  $S_3 = S_1$ , but the change in momentum the snow sheet experiences due to the change in direction and the reduction in velocity caused by the frictional resistance, causes  $S_3 = cS_1$ .

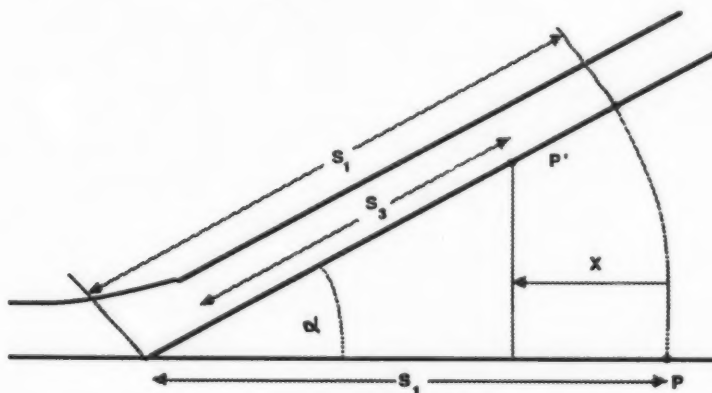


Figure A.1

Therefore,

$$X = S_1(1 - c \cos \alpha)$$

$$\frac{dX}{dt} = \frac{DS_1}{dt}(1 - c \cos \alpha)$$

$$V_x = V_1(1 - c \cos \alpha)$$

Now, the force on the plow due to the change in momentum is:

$$\begin{aligned} F_x &= \dot{m} \Delta V_x \\ &= (\rho A V_1)(V_1(1 - c \cos \alpha) - 0) \\ &= \rho A V_1^2 (1 - c \cos \alpha) \end{aligned}$$

Also, the power is:

$$\begin{aligned} P &= F_x V_1 \\ &= \rho A V_1^3 (1 - c \cos \alpha) \end{aligned}$$

To determine the constant  $c$ , consider an elemental particle of the snow sheet (see Figure A.2).

$$\sum F_i: dm \ddot{i} = -F_f - dm g \sin \alpha$$

Since

$$dm = \rho A di$$

$$di = V_i dt$$

$$\ddot{i} = dV_i/dt$$

then

$$F_f = -\rho A di (dV_i + g \sin \alpha)$$

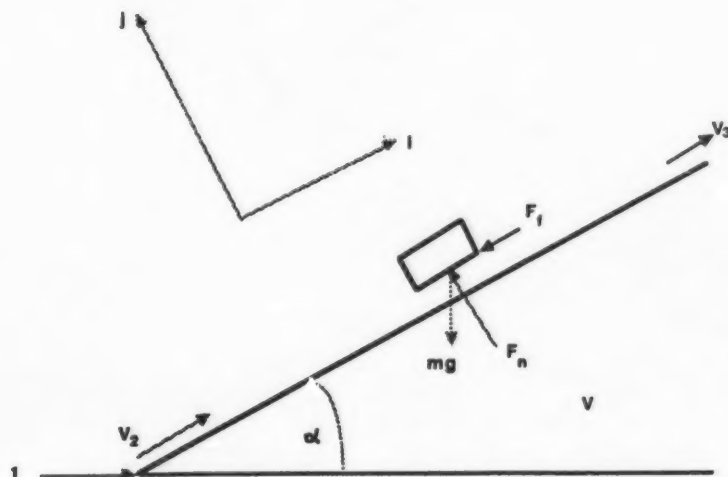


Figure A.2

Also,

$$\sum F_j: dm \ddot{j} = 0 = F_n - dm g \cos \alpha$$

$$F_n = \rho k A d i (g \cos \alpha)$$

if

$$F_f = \mu F_n$$

$$d\dot{V}_i di = -g(\mu \cos \alpha + \sin \alpha) di$$

Integration gives:

$$\frac{1}{2} V_i^2 = -g(\mu \cos \alpha + \sin \alpha) i + K$$

$$\text{at } i = 0, V_i = V_2 \quad K = \frac{1}{2} V_2^2$$

$$\text{at } i = 1, V_i = V_1 = c V_2$$

$$\frac{1}{2} c^2 V_2^2 = -g(\mu \cos \alpha + \sin \alpha) 1 + \frac{1}{2} V_2^2$$

$$c = \sqrt{\frac{V_2^2 - 2gl(\mu \cos \alpha + \sin \alpha)}{V_1^2}}$$

To determine  $V_2$ , consider the change in momentum at the leading edge of the wedge (refer again to Figure A.2):

$$\sum F_i = \rho A V_1 (V_2 - V_i \cos \alpha)$$

$$\sum F_j = \rho A V_1 (0 - V_i \sin \alpha)$$

$$\sum F_i = -\mu \sum F_j$$

$$V_2 - V_i \cos \alpha = -\mu V_i \sin \alpha$$

$$V_2 = V_i (\cos \alpha - \mu \sin \alpha)$$

Substitution gives:

$$c_s = c = \sqrt{(\cos \alpha - \mu \sin \alpha)^2 - \frac{2gl(\mu \cos \alpha + \sin \alpha)}{V_1^2}}$$

It can be seen that the constant depends on two parts:

$(\cos \alpha - \mu \sin \alpha)^2$  : portion due to change in direction of the snow sheet

$\frac{2gl(\mu \cos \alpha + \sin \alpha)}{V_1^2}$  : portion due to normal force caused by gravity

A similar analysis for the vertical wedge gives:

$$c_v = c = (\cos \beta - \mu \sin \beta)$$

This term will be recognized as the portion due to the change in direction of the snow. The other term is not present because there is no normal force due to gravity acting on the vertical wedge.

Note that the constant  $c$  for the elevation wedge has been renamed  $c_e$  in order to differentiate it from the constant for the horizontal wedge.

The total force on the train (due to the snow plow) is then:

$$\begin{aligned} F_t &= F \text{ due to elevation wedge} + F \text{ due to 2 vertical wedges} \\ &= \rho A_e V_1^2 (1 - c_e \cos \alpha) + 2 \times \rho A_v (c_v V_1)^2 (1 - c_v \cos \beta) \end{aligned}$$

If one assumes  $A_e = 2A_v = A$ , then

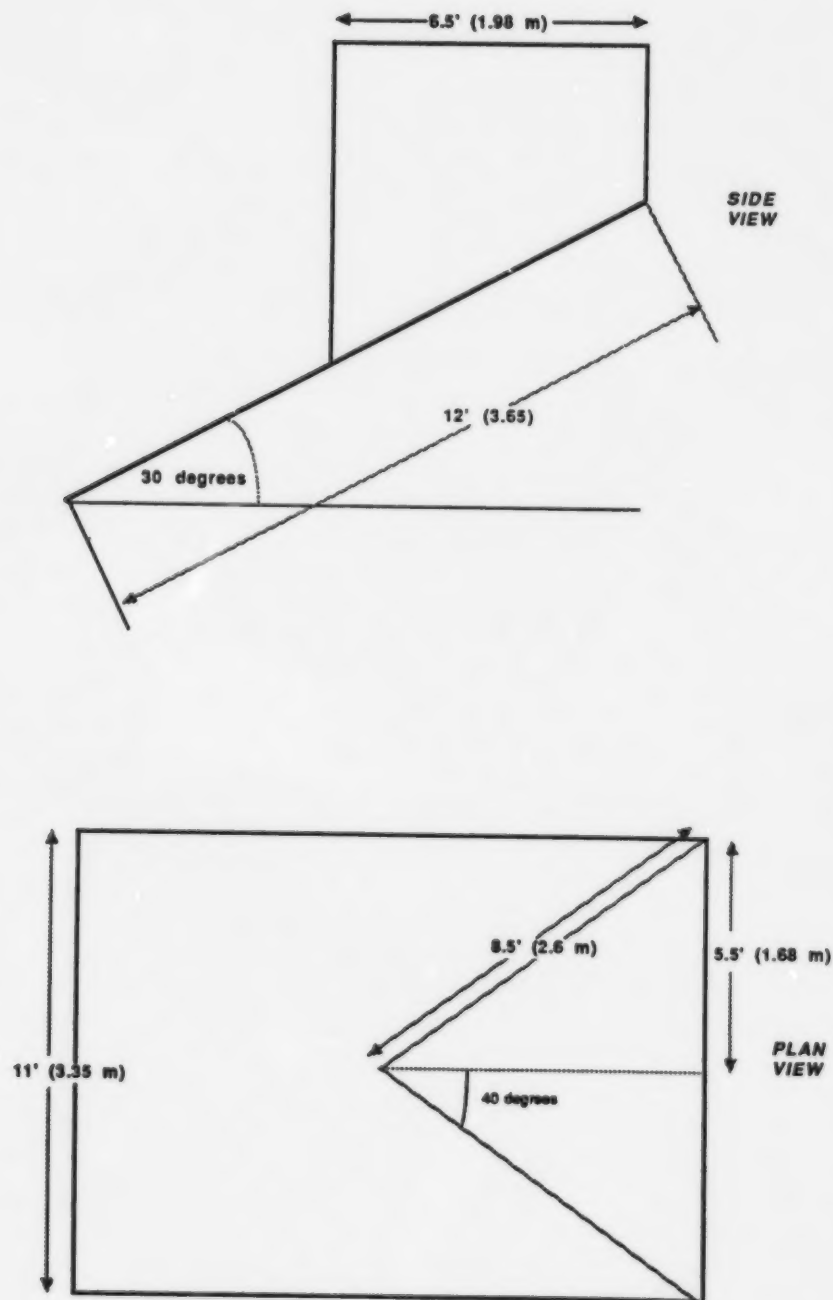
$$F_t = \rho A V_1^2 (1 - c_e \cos \alpha + c_v^2 (1 - c_v \cos \beta))$$

where:

$$c_e = \sqrt{(\cos \alpha - \mu \sin \alpha)^2 - \frac{2gl(\mu \cos \alpha + \sin \alpha)}{V_1^2}}$$

$$c_v = (\cos \beta - \mu \sin \beta)$$

The values estimated for the base case simulation runs are illustrated in Figure A.3.



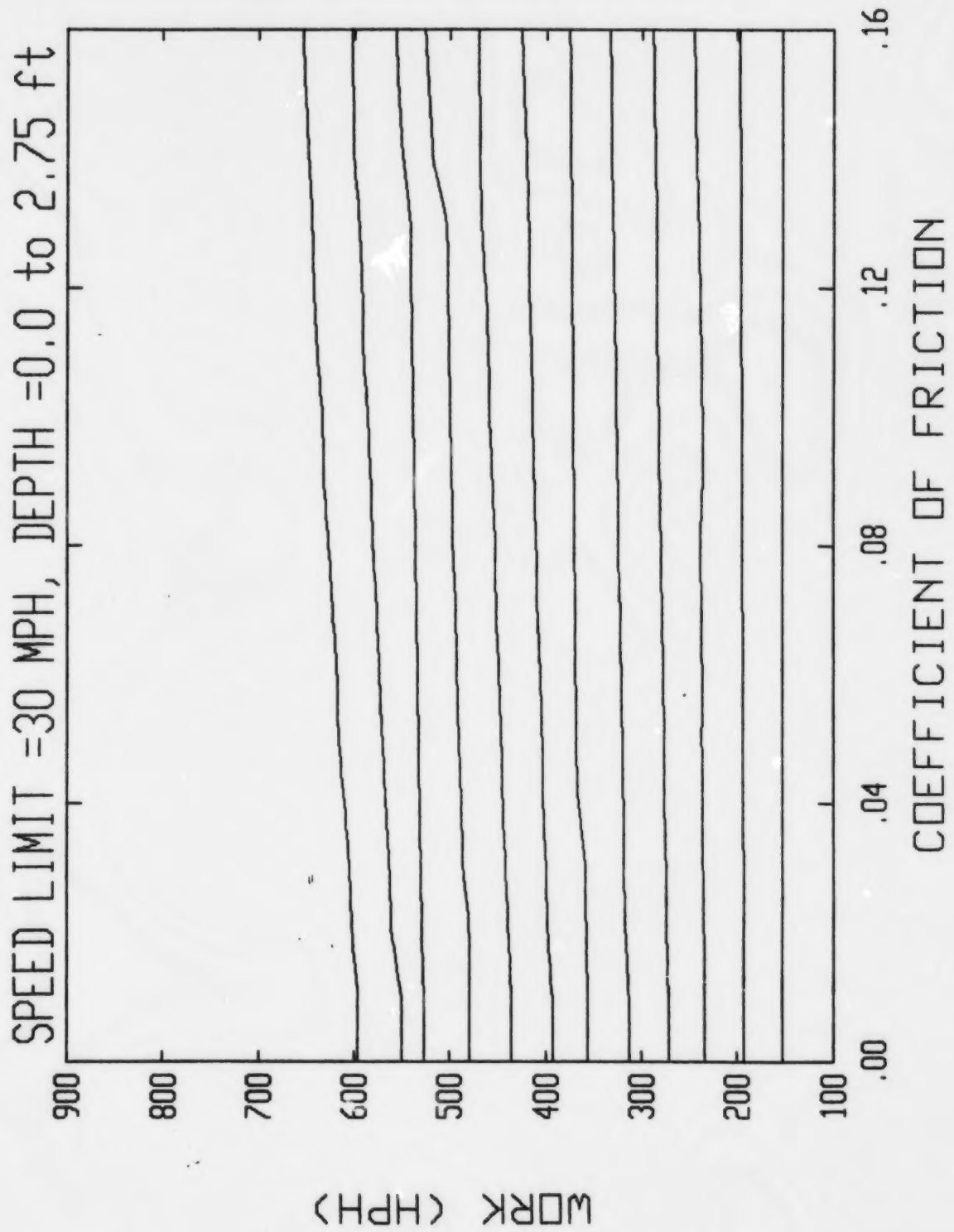
Simplified Test Plow

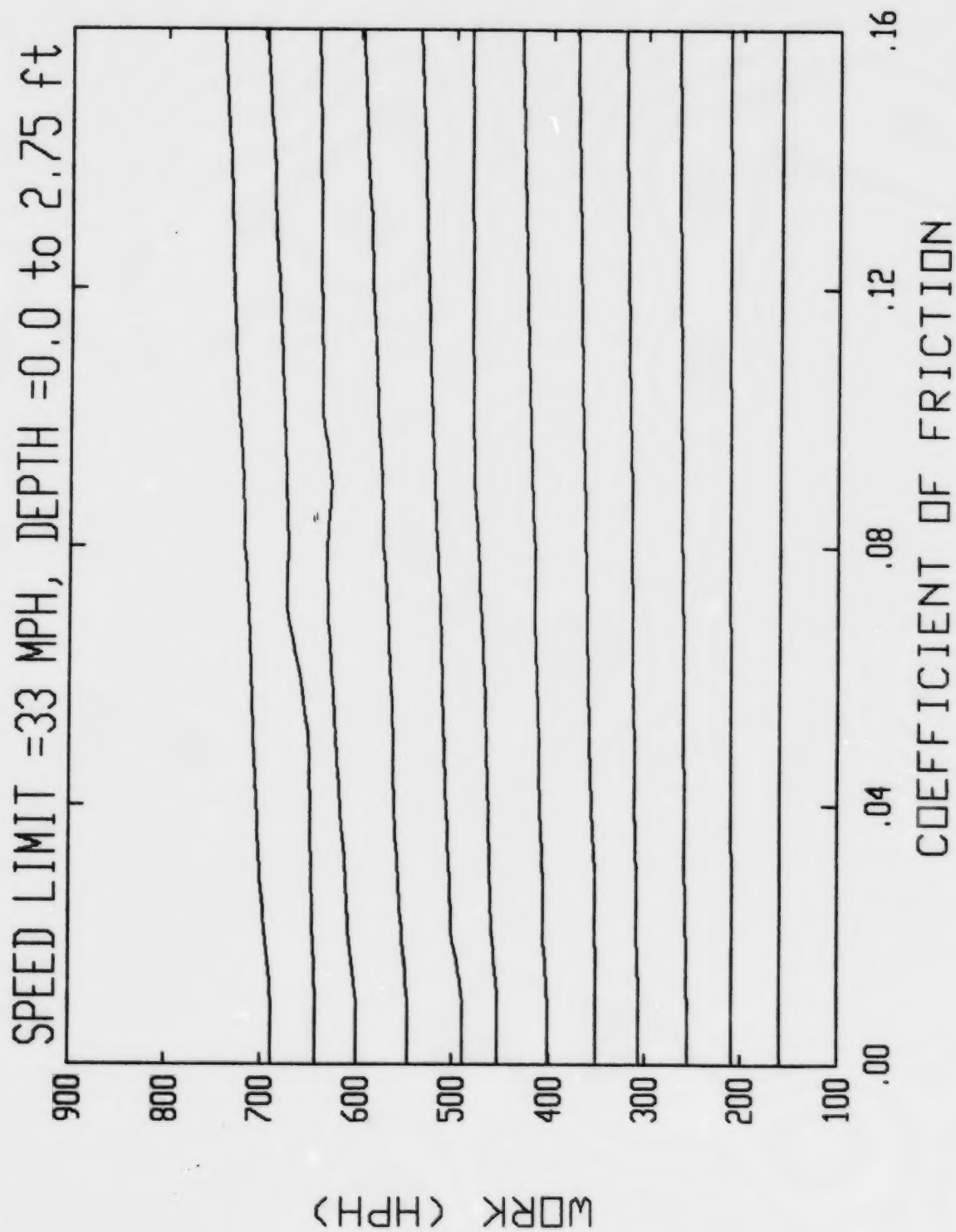
Figure A.3

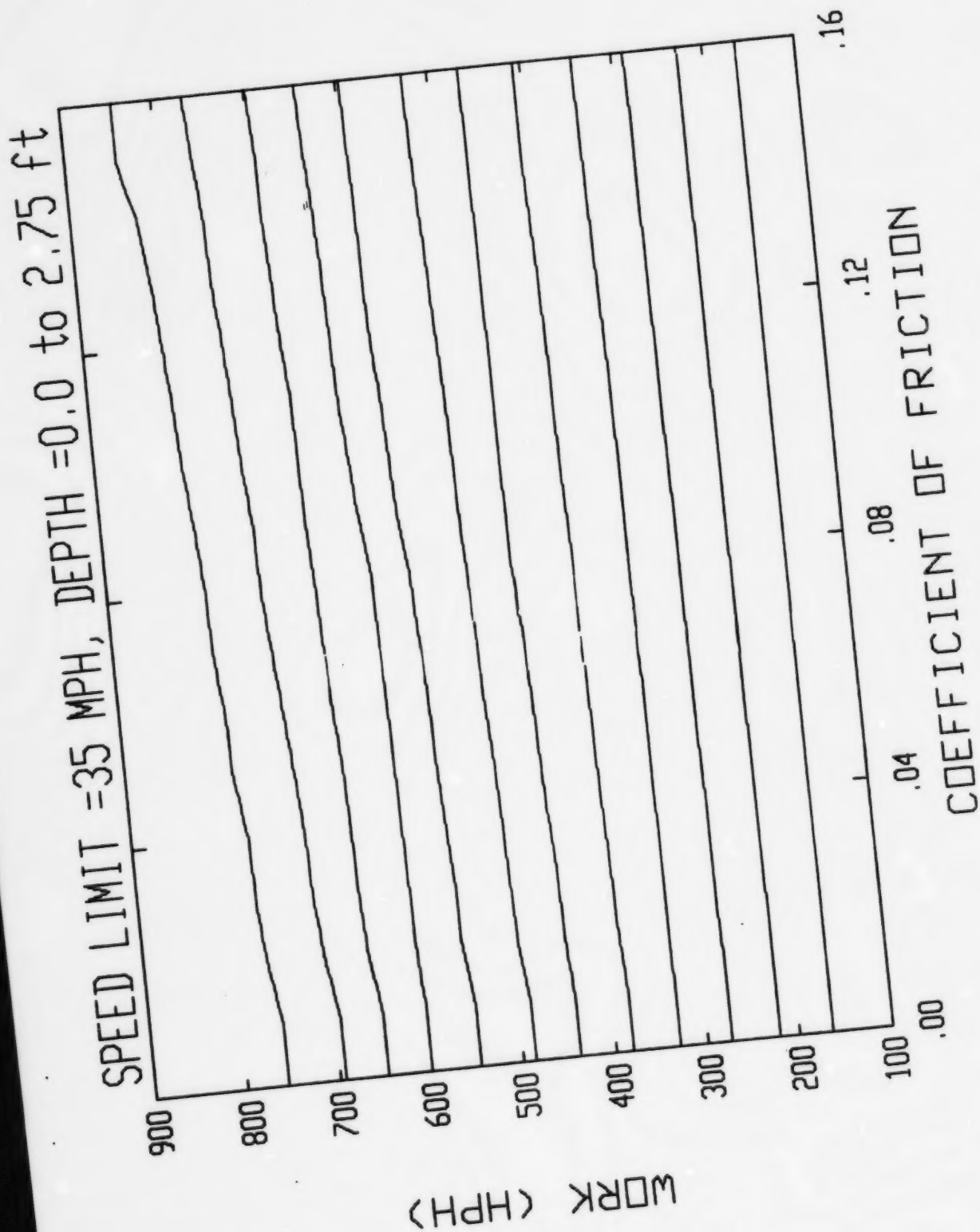


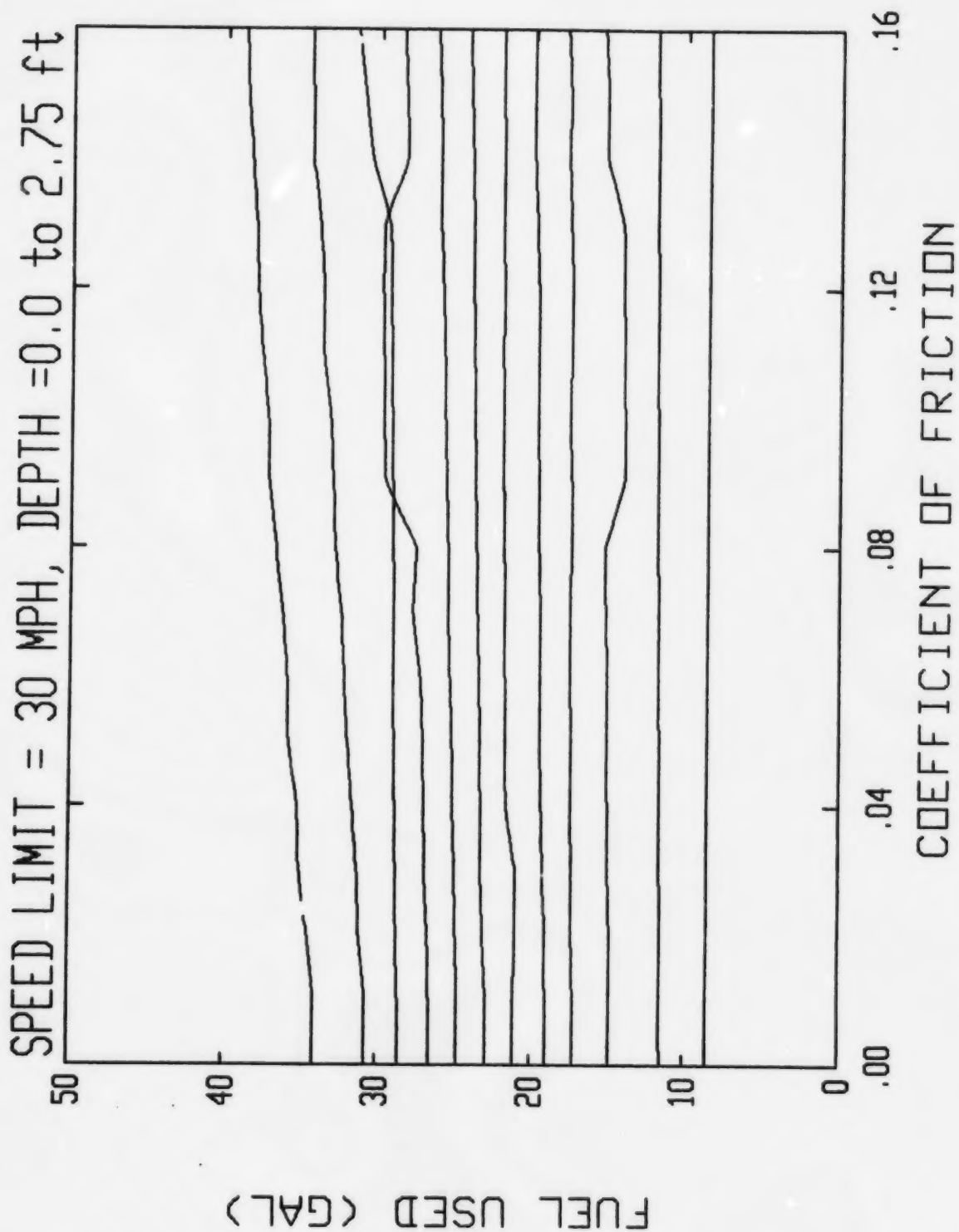
**APPENDIX B**  
**FUEL CONSUMPTION/NETWORK PLOTS**

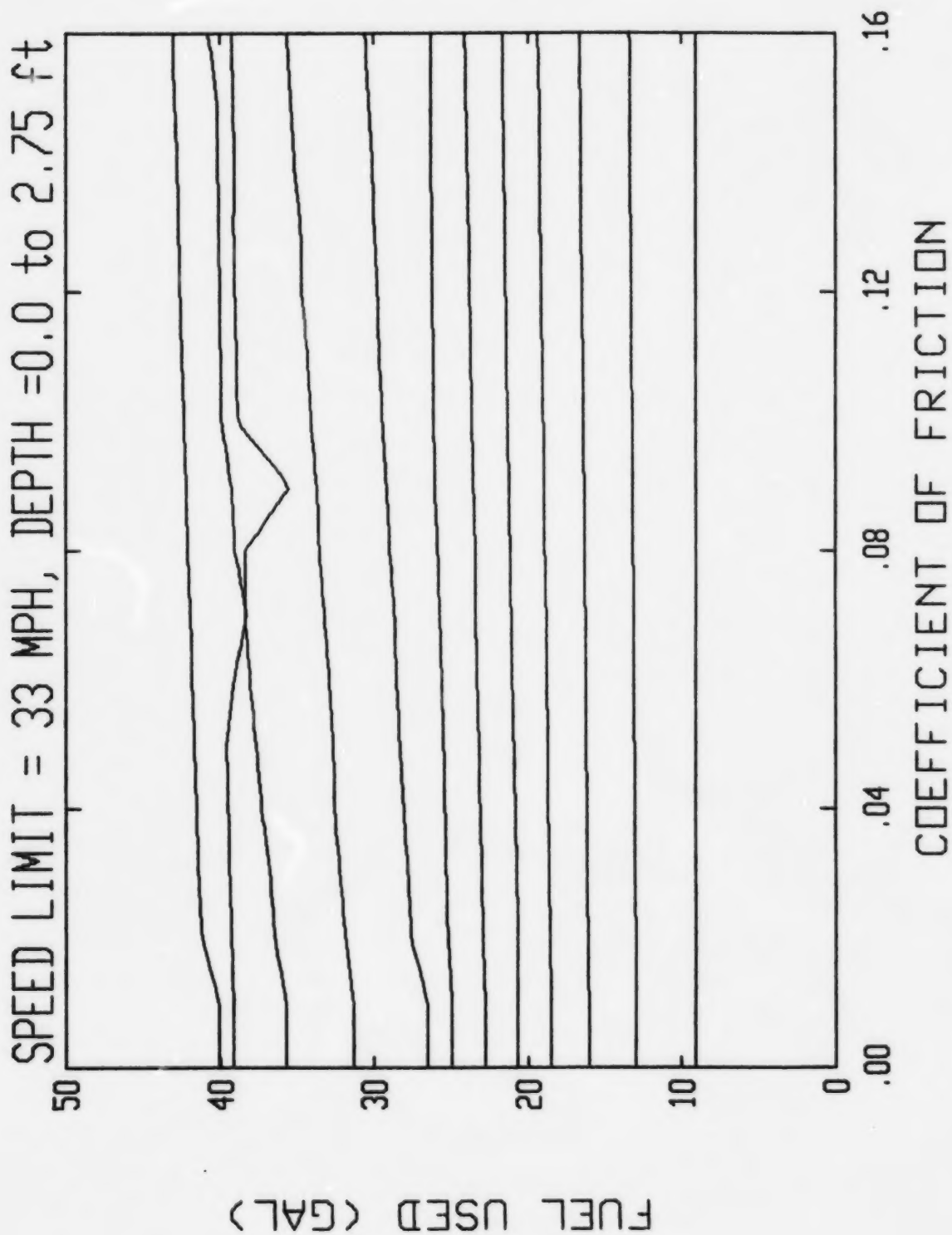


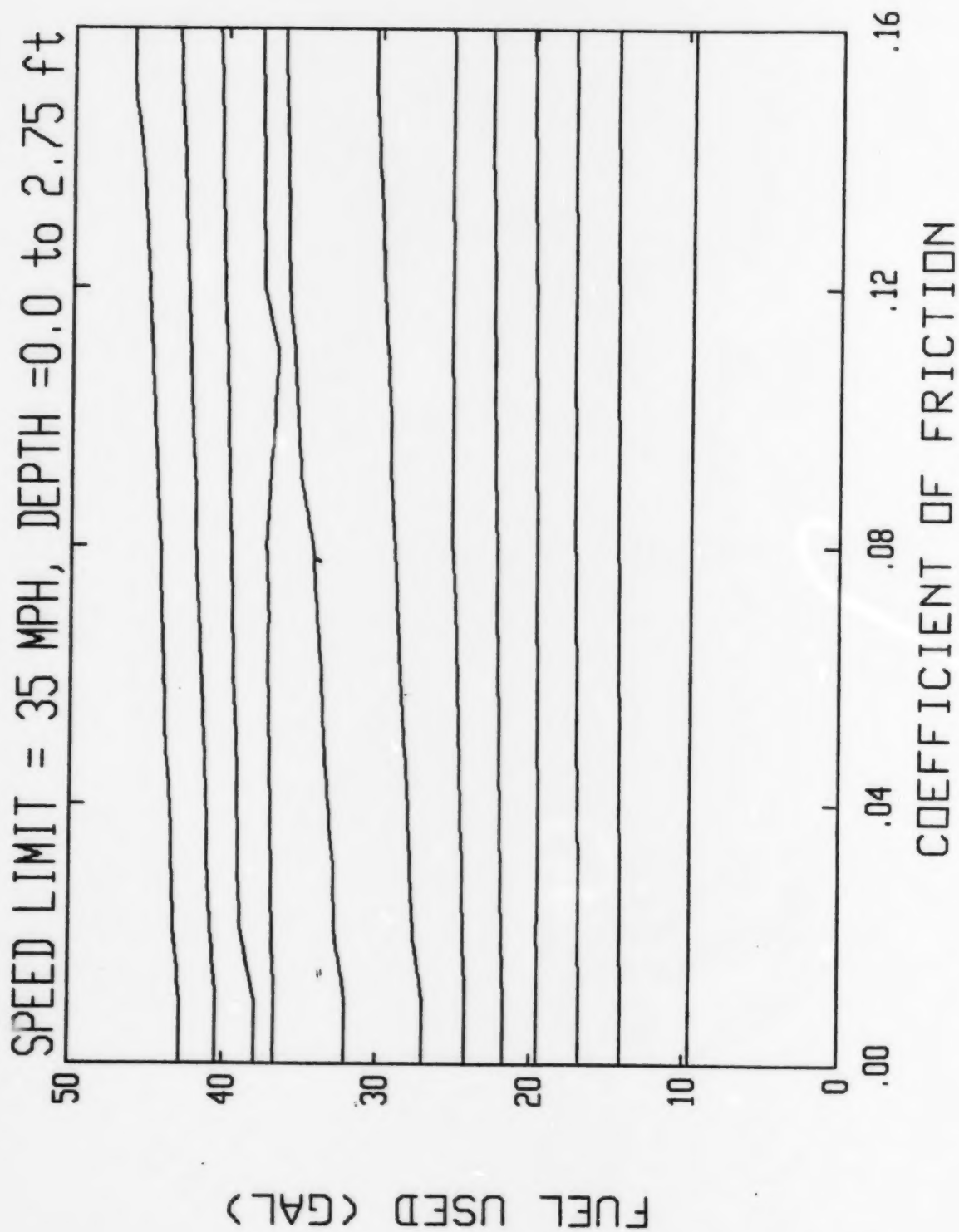


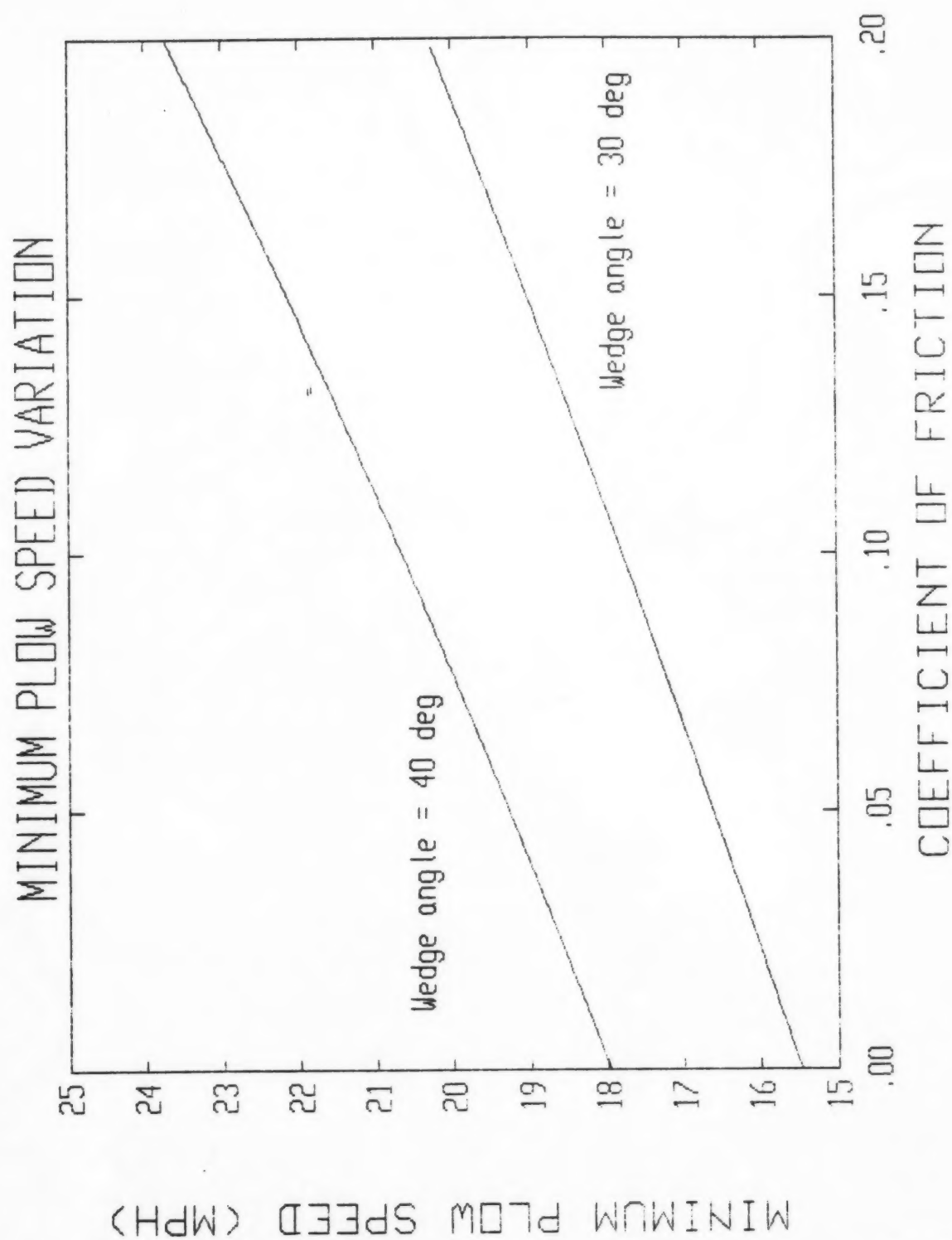




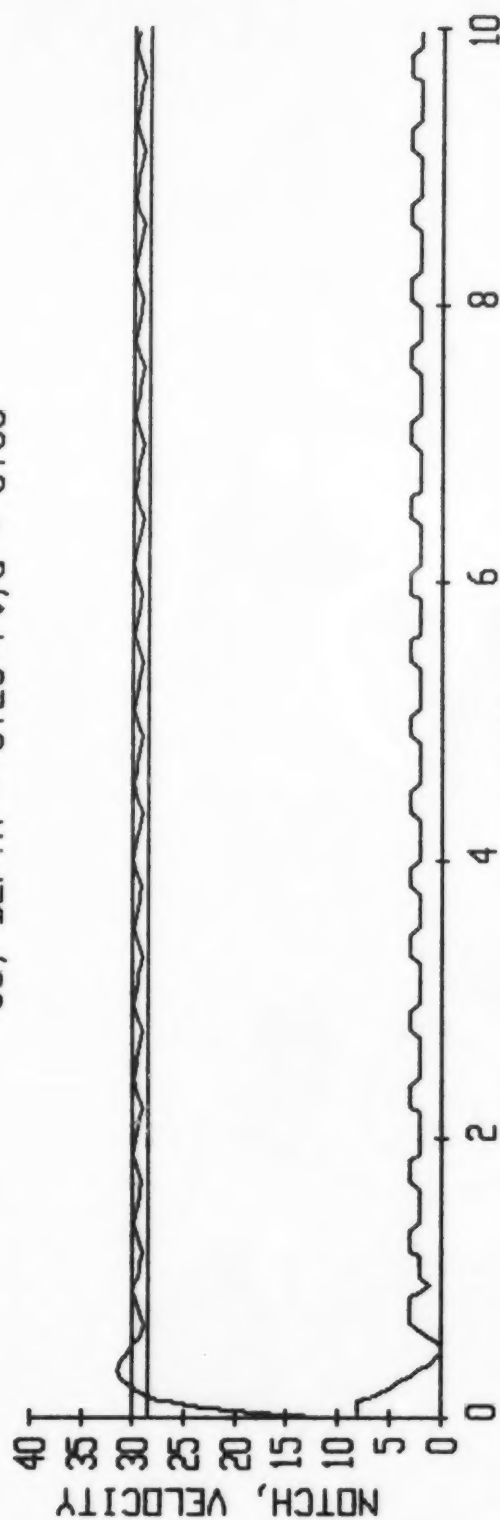




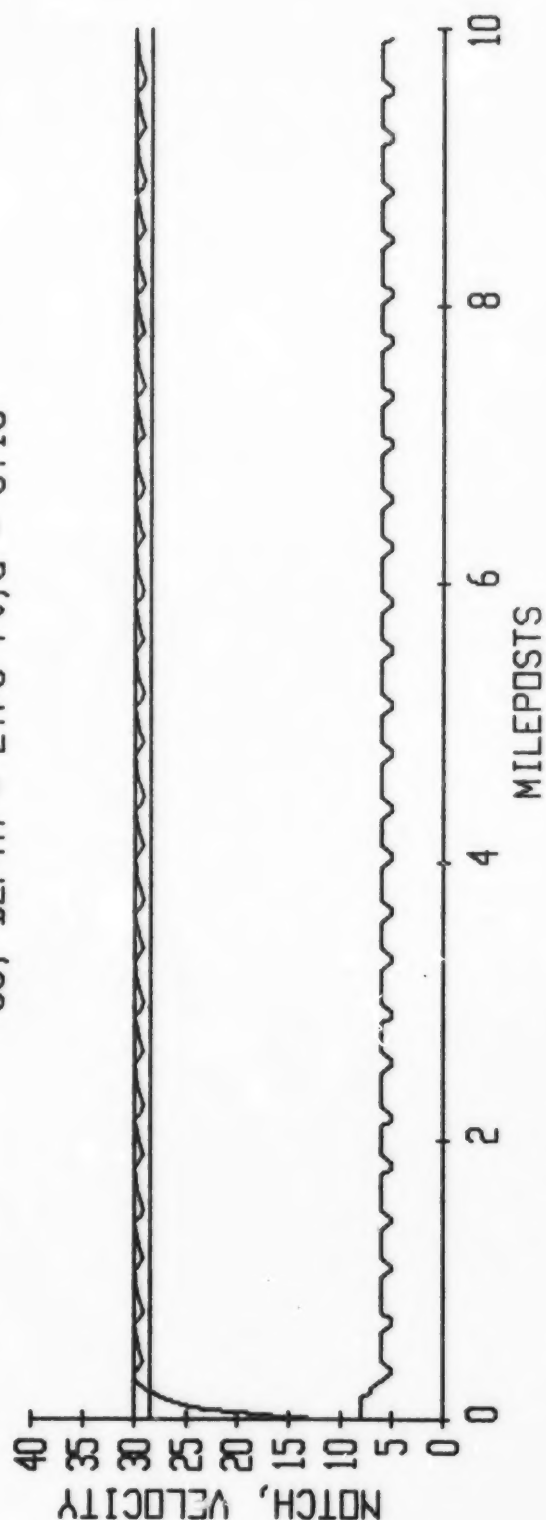




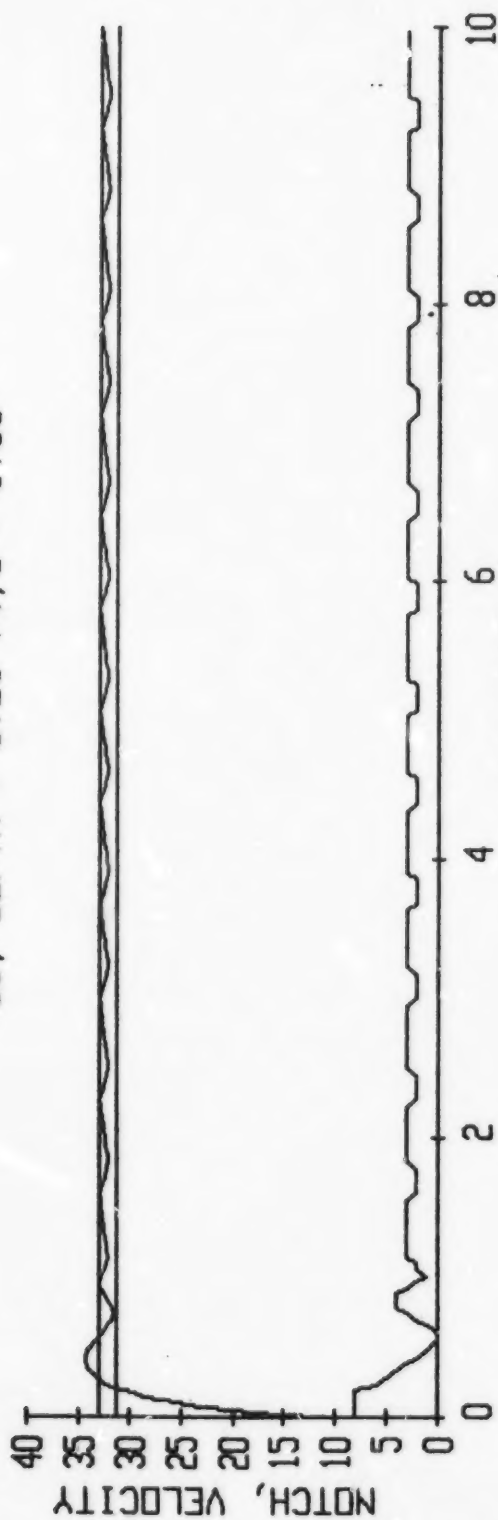
30, DEPTH = 0.25 ft,  $u = 0.00$



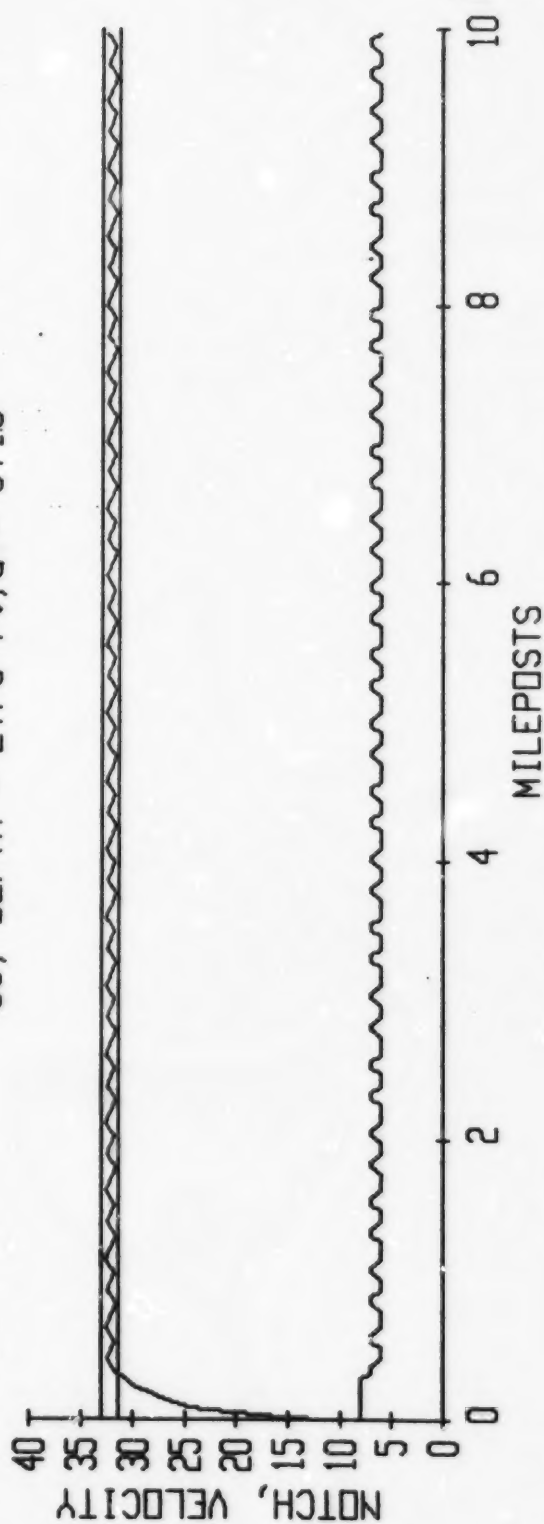
30, DEPTH = 2.75 ft,  $u = 0.16$



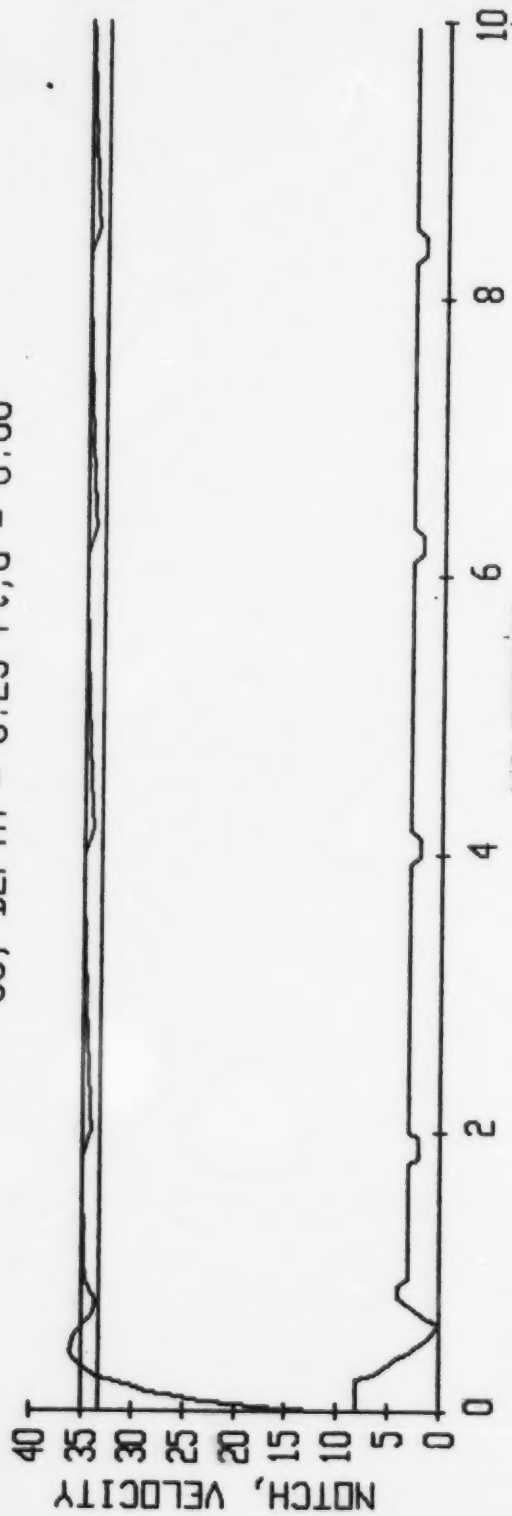
33, DEPTH = 0.25 ft,  $u = 0.00$



33, DEPTH = 2.75 ft,  $u = 0.16$



35, DEPTH = 0.25 ft,  $u = 0.00$



35, DEPTH = 2.75 ft,  $u = 0.16$

